

Kristian M Lien (CEOTO AS)

CO₂ emissions from Biofuels and District Heating in Zero Emission Buildings (ZEB)



SINTEF Academic Press

Kristian M Lien (CEOTO AS)

CO₂ emissions from Biofuels and District Heating in Zero Emission Buildings (ZEB)



ZEB Project report 10 – 2013

ZEB Project report no 10
Kristian M Lien (CEOTO AS)
CO₂ emissions from Biofuels and District Heating in Zero Emission Buildings (ZEB)

Keywords:

Zero Emission Building, CO₂ emission factors, Biofuel, District Heating, Abeldo effect

ISSN 1893-157X (online)

ISSN 1893-1561

ISBN 978-82-536-1336-9 (pdf), 2013

ISBN 978-82-536-1337-6 (printed), 2013

Photo cover: Mette Langeid

28 copies printed by AIT AS e-dit

Content: 100 g Scandia

Cover: 240 g Trucard

© **Copyright SINTEF Academic Press and Norwegian University of Science and Technology 2013**

The material in this publication is covered by the provisions of the Norwegian Copyright Act. Without any special agreement with SINTEF Academic Press and Norwegian University of Science and Technology, any copying and making available of the material is only allowed to the extent that this is permitted by law or allowed through an agreement with Kopinor, the Reproduction Rights Organisation for Norway. Any use contrary to legislation or an agreement may lead to a liability for damages and confiscation, and may be punished by fines or imprisonment.

Norwegian University of Science and Technology ²⁾

N-7491 Trondheim

Tel: +47 22 73 59 50 00

www.ntnu.no

www.zeb.no

SINTEF Building and Infrastructure Trondheim ¹⁾

Høgskoleringen 7 b, POBox 4760 Sluppen, N-7465 Trondheim

Tel: +47 22 73 59 30 00

www.sintef.no/byggforsk

www.zeb.no

SINTEF Academic Press

c/o SINTEF Building and Infrastructure Oslo

Forskningsveien 3 B, POBox 124 Blindern, N-0314 Oslo

Tel: +47 22 96 55 55, Fax: +47 22 69 94 38 and 22 96 55 08

www.sintef.no/byggforsk

www.sintefbok.no

Acknowledgement

This report has been written within the Research Centre on Zero Emission Buildings (ZEB). The authors gratefully acknowledge the support from the Research Council of Norway, BNL – Federation of construction industries, Brødrene Dahl, ByBo, Caverion Norge, DiBK – Norwegian Building Authority, DuPont, Enova SF, Entra, Forsvarsbygg, Glava, Husbanken, Hydro Aluminium, Isola, Multiconsult, NorDan, Norsk Teknologi, Protan, Skanska, Snøhetta, Statsbygg, VELUX, and Weber.

Abstract

Carbon Debt and **Carbon Payback time** have recently been introduced into the Norwegian debate on greenhouse gas emissions, challenging the established view that Biofuels are carbon neutral. This report demonstrates that these new concepts are primarily a reflection of how the temporal system boundaries for CO₂ emissions from biofuels are viewed. In a short term perspective it is possible that CO₂ emissions from biofuels may have a non-zero short term climate effect, even though biofuels will be carbon neutral on the order of a century. Two alternative, more useful new concepts for analysis of climate effects of biofuels are described in this report: The **Global Warming Potential (GWP) index for biofuels** and the **Albedo effect**. In particular, one should be aware that the Albedo effect may overshadow the effects of CO₂ emissions from biofuels. Finally, the report describes how waste incineration based District Heating systems may have greenhouse gas emissions on the same order as natural gas.

Contents

1. SUMMARY.....	6
1.1 BIOFUELS.....	6
1.2 DISTRICT HEATING.....	7
2. A BRIEF INTRODUCTION TO CO₂ EMISSIONS AND GLOBAL WARMING.....	8
2.1 CO ₂ EQUIVALENCE.....	10
3. BIOFUELS	13
3.1 THE REVISED EU FRAMEWORK - ASSUMING CARBON NEUTRALITY	13
3.2 CARBON NEUTRALITY VS. CARBON DEBT AND PAYBACK TIME	14
3.3 THE GWP _{BIG} INDEX	16
3.4 THE ALBEDO EFFECT – CLIMATE IMPACT <i>WITHOUT</i> GREENHOUSE GAS EMISSIONS.....	17
3.5 CONCLUSIONS AND RECOMMENDATIONS FOR BIOFUELS.....	19
4. DISTRICT HEATING.....	21
4.1 DISTRICT HEATING - VIEWED AS WASTE HEAT UTILIZATION.....	21
4.2 CAN DISTRICT HEATING PARTLY BE VIEWED AS UNDESIRABLE BYPRODUCT DESTRUCTION?.....	21
4.3 THE FOSSIL FUEL CONTENTS OF INCINERATED WASTE	22
4.4 THE <i>PRESENT</i> COMPOSITION OF DISTRICT HEATING IN NORWAY	24
4.5 THE <i>FUTURE</i> COMPOSITION OF DISTRICT HEATING IN NORWAY	25
4.6 CONCLUSIONS AND RECOMMENDATIONS ON DISTRICT HEATING.....	26

APPENDICES

1. Summary

CO₂ emissions from Biofuels and District Heating may be viewed in many different ways, depending on the system boundaries applied. Recently, new notions such as Carbon Debt and Carbon Payback time have been introduced into the Norwegian debate on greenhouse gas emissions, challenging the established view that Biofuels are carbon neutral.

This report provides a discussion of these new concepts, and point out that they are primarily a reflection of how the temporal system boundaries for CO₂ emissions from biofuels are viewed: In a Tipping Point perspective ¹ on greenhouse gas emissions it is possible that CO₂ emissions from biofuels may have a non-zero short term climate effect, even though biofuels will be carbon neutral on the order of a century. But if the short horizon tipping point perspective is applied, one should to be consistent also re-evaluate the short term perspective on all greenhouse gases. We point out that methane emissions, e.g. from the petroleum sector, in a tipping point perspective would add on the order of 10 mill. tons of CO₂ equivalents to the Norwegian annual greenhouse emission.

We point to the new notion of a Global Warming Potential (GWP) index for biofuels, a new framework for calculation of the climate effects of biofuels on both shorter and longer terms. The GWP index also includes the natural absorption of CO₂ – anthropogenic or biogenic, into the oceans. This ocean absorption effect is neglected by present Carbon Payback time calculations for biofuels, also those recently presented by Norwegian authorities, yielding calculated payback times that appear to be on the order of twice the value of payback times where ocean absorption is included.

Finally we introduce the notion of the Albedo effect on biofuel emissions. Harvesting of biofuels alters the surface properties of the harvested area, and this affects the energy balance of the area. This effect is particularly high where biomass harvesting results in snow covered white plains instead of dark energy absorbing forests. We point to recent publications that indicate that the Albedo effect may overshadow the effects of CO₂ emissions from biofuels.

This report does not provide a comprehensive review of all climate effects of biofuels. We have e.g. decided not to include present discussions in the scientific communities regarding the effects that forests have on aerosol formation (i.e. terpene emissions) and thereby indirectly on cloud formation. We have also decided to leave out the new and emerging discussions on how forests may contribute to long term soil carbon sequestration (i.e. glomalin production).

1.1 Biofuels

We conclude that for biofuels, it is too early to state whether their harvesting and use will result in positive or negative global warming effects. We therefore propose that, until further notice, biofuels should in principle still be viewed as climate neutral. Consequently, we recommend that the recently revised EU procedure for calculation of emissions from biofuels should be applied.

For solid and gaseous biofuels a number of selected default values computed using this procedure are listed in the table below:

¹ i.e. if we expect to reach CO₂ levels representing threshold that will lead to irreversible climate changes in an matter of decades rather than centuries

Specific CO ₂ emissions from selected biofuels - default values		
BIOFUEL TYPE	gCO ₂ /MJ	gCO ₂ /kWh
GROT wood chips	1	3,6
EU Wood chips	4	14,4
GROT pellets / briquettes (1)	2	7,2
EU Wood pellets / briquettes (1)	4	14,4
EU Wood pellets / briquettes (2)	22	79,2
Wheat straw	2	7,2
Biogas from wet manure	8	28,8
Biogas from dry manure	7	25,2
(1) Using wood as process fuel		
(2) Using natural gas as process fuel		
GROT = Wood residue		
EU Wood= European temperate		

Typical present *liquid* biofuels in the EU market (i.e. 1st generation liquid biofuels) have CO₂-equivalent emissions in the ranges:

- Ethanol: 24 g/MJ (sugar cane based) – 70 g/MJ (wheat based)
- Biodiesel: 14 g/MJ (waste oils) – 68 g/MJ (palm oil with unspecified process fuel)
- Oils: 14 g/MJ (waste oils) – 62 g/MJ (hydrotreated palm oil with unspecified process fuel)

For 2nd generation biofuels, which are not yet present in significant amounts in the EU market, the following emissions are estimated:

- Ethanol: 13 g/MJ (wheat straw) – 25 g/MJ (farmed wood)
- Biodiesel: 4 g/MJ (waste wood) – 6 g/MJ (farmed wood)
- DME and methanol: 5 g/MJ (waste wood) – 7 g/MJ (farmed wood)

Borregaard in Sarpsborg, Norway, produce limited amounts of wood based ethanol with reported specific CO₂-emissions in the range 14 g/MJ (96% ethanol) – 29 g/MJ (99% ethanol).

1.2 District Heating

We recommend that in general, district heating should not be viewed as emission free waste heat utilization, but should instead be analyzed on the basis of the **actual** greenhouse gas emissions associated. Neither should waste incineration based district heating be viewed as inevitable byproduct destruction: Waste for incineration is presently an *internationally tradable commodity*, and should preferably be utilized where it gives maximum energy per unit greenhouse gas emitted ².

With the present composition of incinerated waste (50% fossil on energy basis), specific greenhouse gas **emissions from waste incineration based district heating are comparable to combustion of natural gas**. Waste incineration based district heating systems do therefore presently have only minor differences in specific greenhouse gas emissions between base load (waste) and peak load (gas). Future reductions in peak load specific emissions are possible if present natural gas is substituted by biofuels. Future reductions in base load specific emissions would either require that the present percentage of waste incineration in district heating is reduced, or that improved recycling solutions are found for major portions of plastics presently found in waste. Alternatives to waste incineration that could reduce base load greenhouse gas emissions could for example include geothermal heat, solar heat, industrial waste heat, as well as the less expensive ones among the biofuels.

² Presently, it appears that e.g. Swedish district heating networks get on the order of 10 - 20% more energy out of incinerated waste than typical Norwegian installations.

2. A brief introduction to CO₂ emissions and global warming

The ZEB research center has defined a zero emission building as one that compensates for CO₂ emissions from the production of materials and construction by producing more energy than the building uses for operation. This extra energy offsets CO₂ emissions during the lifetime of the building, as illustrated in Figure1 below.

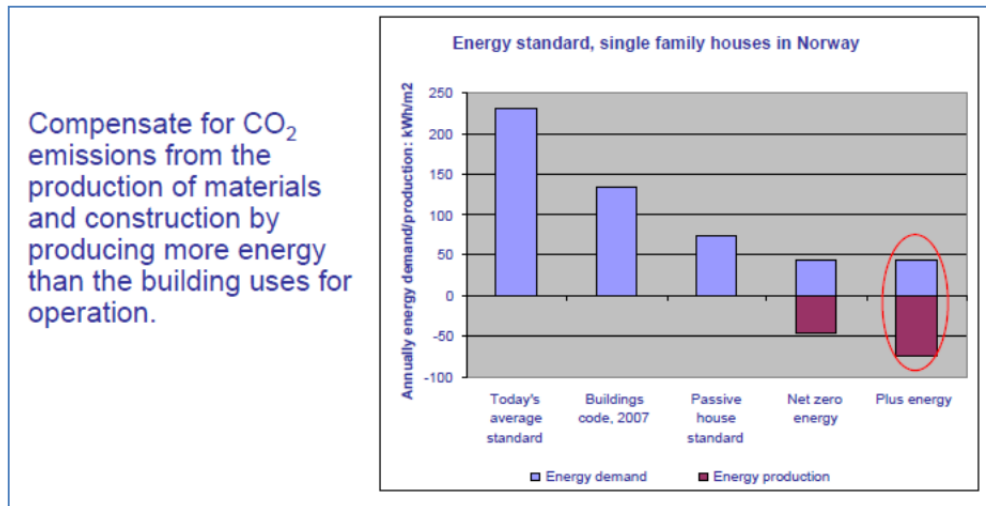


Figure 1 ZEB Zero emission definition

It must therefore be established how large CO₂ emissions the use of various energy sources and energy carriers result in when used in a zero emission building. Comparing CO₂ emissions from the building process with CO₂ emissions or offsets over the entire lifetime of the building, it is important to recognize that greenhouse gases emitted to the atmosphere will decay over time. This is exemplified in Figure 2 below:

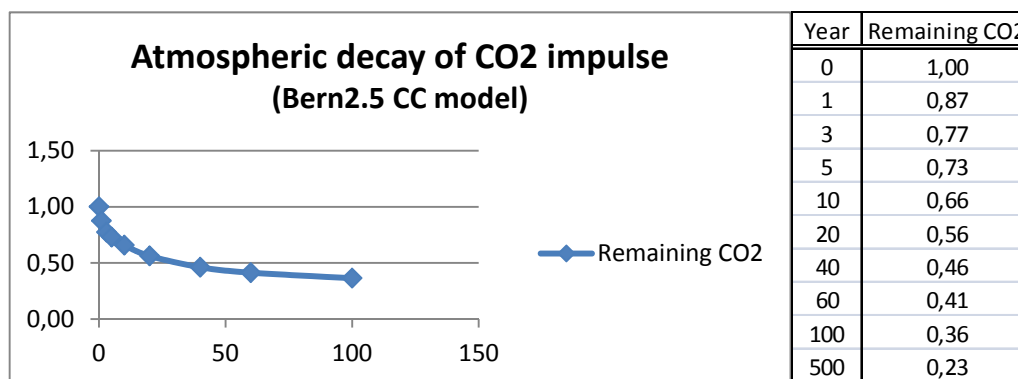


Figure 2 Atmospheric decay of CO₂ according to Bern2.5

If all the CO₂ emitted in the process of making all constituent materials and erecting the building is viewed as a CO₂ pulse emission to the atmosphere in year zero³, then **only half of this CO₂ will remain in the atmosphere after 30 years**. The rest has been absorbed by oceans and the biosphere. These calculations are based on the Bern2.5 Carbon Cycle model⁴, a widely used and recognized

³ a reasonable assumption if the production and erection period is short compared to the building life time

⁴ Joos, F., et al., 2001. Global warming feedbacks on terrestrial carbon uptake under the Intergovernmental Panel on Climate Change (IPCC) emission scenarios. *Global Biogeochem. Cycles*, **15**, 891-908, 2001

aggregate carbon cycle model. It is important to account for this kind of exponential decay, highly nonlinear as it is, when emissions and offsets at different points in time are compared.

It is also important to recognize that fossil fuel consumption for energy purposes throughout the lifetime of a building produces a **stream** of CO₂-emissions that causes **accumulation** in the atmosphere: Parts of the emitted CO₂ is absorbed according to the above exponential decay function, but unless the emissions also decrease exponentially with time, there will be net accumulation in the atmosphere with time. This is illustrated in Figure 3 below for the case of *constant* emissions over time.

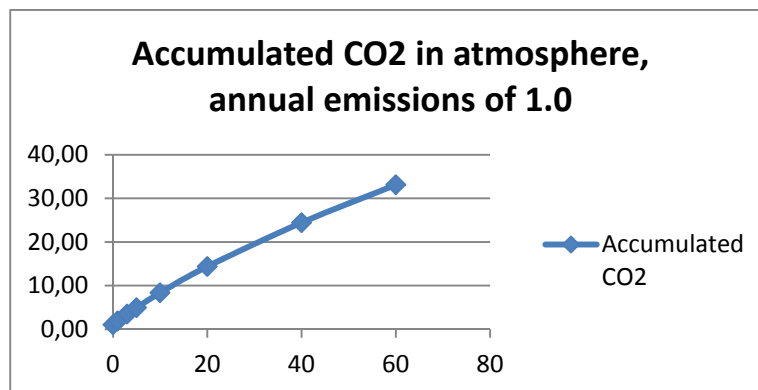


Figure 3 Accumulation of CO₂ with constant annual emissions, according to Bern2.5

The global warming potential of greenhouse gases is in general depends logarithmically on the greenhouse gas concentrations. IPCC presented revised data for the global warming potential of CO₂ in their 4th assessment report⁵. These data, presented in Figure 4, are valid around a CO₂ concentration of 378 ppm:

20 years	2,47E-14	W m-2 yr (kg CO2)-1
100 years	8,69E-14	W m-2 yr (kg CO2)-1
500 years	2,86E-13	W m-2 yr (kg CO2)-1

Figure 4 Global warming potential of CO₂ for different time horizons

In the above form, it is hard to relate these global warming potentials to anything practical, but if we multiply these numbers with the surface area of the earth (approx. 510 mill. km²) and convert them to MWh and tons of CO₂ emissions per year, we get the following results, which may be compared to CO₂ emissions resulting from energy production from any fuel:

⁵ IPCC: Forster, P., V. Ramaswamy, P. Artaxo, T. Bernsten, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, 2007: Changes in Atmospheric Constituents and in Radiative Forcing. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

20 years	110	MWh/år per tonn CO ₂ /år
100 years	388	MWh/år per tonn CO ₂ /år
500 years	1278	MWh/år per tonn CO ₂ /år

Figure 5 Global warming potential of CO₂, converted

As an example, the cleanest of the fossil fuels – natural gas, will give 4– 5 MWh energy (i.e. heat) per ton of CO₂ emitted annually. Over a 20 year period this annual emission gives us energy amounting to 80 – 100 MWh, and over a 100 year period we get to 400 – 500 MWh. The *annual* global warming potential at year *i* is thus on the same order as the *sum* of energy obtained through all these *i* years. This disturbing “**memory effect**” is a vivid illustration of the problematic long term global warming effects of fossil fuel consumption.

Consumption of biofuels and District Heating is characterized by having specific CO₂ emissions that may depend on **system boundaries** – both spatial and temporal. The **spatial** system boundary debate is well known from the debate on specific greenhouse gas emissions from electricity consumption: Should the spatial system boundaries be *local, national, Nordic, European or global*? Similar questions are facing us when we consume biofuels or District Heating.

The **temporal** system boundary debate does however have a set of concerns associated with it that are presently primarily recognized as being related to biofuels: The use of biofuels *today* may impact on the net emission of greenhouse gases in the *future*. And depending on the time frame adopted; immediate, 1-year, 10-year, 50-year, 100-year, 500-year or infinite, computed net greenhouse gas emissions from biofuels may exhibit substantial variation. Adding to the complexity of the issue, reliable data from the future do in principle not exist. The temporal system boundary debate is therefore deemed to be based on a set of present modeling assumptions rather than on empirical data.

Above, we have reinterpreted the ZEB term **CO₂ emissions** to imply **greenhouse gas emissions**. This is not a controversial extension: It would presently probably be viewed as a mistake to exclude other known greenhouse gases, e.g. methane, from any comprehensive analysis. We will in our discussion of biofuels later on in this paper have to extend this interpretation even further: The consumption of biofuels may affect global warming even if greenhouse gas emissions are zero. This is so because the harvesting of biofuels will alter the absorption and reflection of sunlight on the harvested areas. This alteration of surface properties has an effect on the earth’s energy balance, with potential impact on global warming. Similar effects may be expected for other applications where surface absorption and reflection is altered in order to capture energy over large surface areas, such as solar energy installations⁶.

2.1 CO₂ equivalence

One of the key accounting concepts used in the Kyoto agreement is the notion of **CO₂ equivalence**. All greenhouse gases are presently characterized by their CO₂ equivalence, methane emissions are e.g. multiplied by 25 to obtain their CO₂ equivalence, and nitrous oxide emissions are similarly multiplied by 298. Methane and nitrous oxide are both stronger greenhouse gases than CO₂.

⁶ Preliminary calculations indicate that present photovoltaic installations may have an “Albedo Payback Time” on the order of three years.

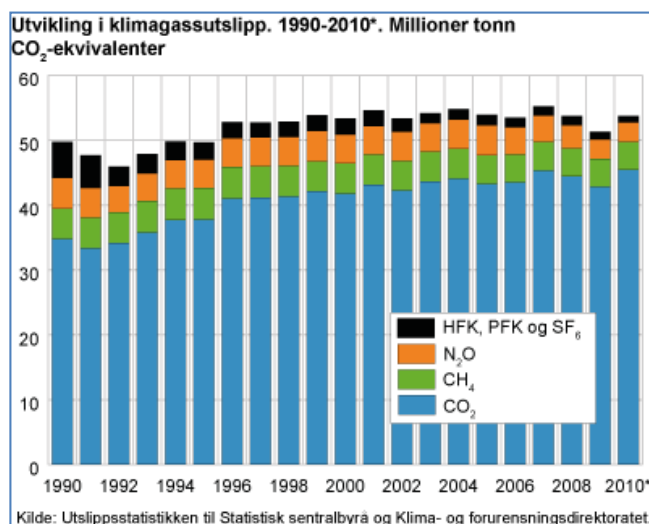


Figure 6 Norwegian greenhouse gas emissions (Source: SSB)

The strict definition of CO₂ equivalence is however *the global warming potential an emission of one ton of a gas has compared to a ton of CO₂ on a 100-years timeframe*. The timeframe is important because different gases have different behavior in the atmosphere over time – some are partially decomposed or altered with time (e.g. methane), others are partially absorbed in oceans and vegetation (CO₂), so the effective residence time that different greenhouse gases will have in the atmosphere will differ from gas to gas. Figure 7 below⁷ illustrates the effect of timeframe on GWP for some greenhouse gases relative to CO₂⁸.

GHG	Lifetime (years)	Radiative efficiency (W m ⁻² ppb ⁻¹)	GWP 20 years	GWP 100 years	GWP 500 years
Carbon dioxide (CO ₂)	na	1.4 × 10 ⁻⁵	1	1	1
Methane (CH ₄)	12	3.7 × 10 ⁻⁴	72	25	7.6
Nitrous oxide (N ₂ O)	114	3.03 × 10 ⁻³	289	298	153

na, not available.

Figure 7 Global warming potential of some greenhouse gases (Source: Cherubini et al.7)

Under the Kyoto agreement, biofuels are considered to be *Carbon Neutral*, even though the combustion of biofuels releases CO₂ to the atmosphere. The justification for this is that in a *100-years timeframe* the biomass harvested and combusted will be replaced by *re-growth of new biomass*, absorbing a similar amount of CO₂ from the atmosphere that was released during harvesting and combustion in the first place.

The adequacy of the 100-year time frame adopted in the Kyoto process has recently been questioned. The notions of global warming *tipping points*, *thresholds* and *positive feedback* mechanisms have brought warnings that we may have to take a less than 100 years perspective on the global warming problem, or it may become too late for change and irreversible global warming will occur.

⁷ Cherubini et al.: CO₂ emissions from biomass combustion for bioenergy: atmospheric decay and contribution to global warming, Global Change Biology Bioenergy, Vol 3, Issue 5, Oct. 2011

⁸ The **absolute** GWP values for CO₂ for 20, 100, and 500 year time horizons are 2.47 × 10⁻¹⁴, 8.69 × 10⁻¹⁴, and 28.6 × 10⁻¹⁴ W m⁻² yr (kg CO₂)⁻¹, respectively, according to the 2007 IPCC report.

These concerns have naturally put the biofuels carbon neutrality assumption under new scrutiny, and new notions such as “bioenergy carbon debt” and “carbon payback time” have been introduced to describe the view that when we combust biomass, an immediate CO₂ emission takes place, that will take decades to “pay back” in the form of CO₂ absorbed into regrowth of new vegetation.

The present discussion on the carbon neutrality of biofuels is however more than anything else a discussion about adequate temporal system boundaries for greenhouse gas emissions, and if carried through consistently as such, this debate may have implications also beyond the biofuels area: Figure 7 illustrates e.g. that methane emissions will have three times their presently assumed impact on global warming if a **20-year timeframe** is adopted instead of the present 100-years timeframe. Figure 6 illustrates that for Norway this could represent an increase in CO₂ equivalent emissions on the order of **10 mill. tons** per year, a major portion of this likely coming from the **petroleum sector**. It is therefore tempting to suggest that biofuel carbon neutrality critics so far may have been barking up the wrong tree.

3. Biofuels

In this report we use the term biofuel for all kinds of bioenergy – solid (pellets, wood chips, wood logs, briquettes, etc.), liquid (bio-oils, bio-ethanol, bio-diesel, etc.) as well as gaseous (biogas, etc.). In this section of the report we will first present work assuming that biofuels are essentially carbon neutral, then we will examine the Carbon Payback Time concept for biofuels, thereafter we will introduce the notion of a Global Warming Potential Index for biofuels, and finally we will point to work examining the impact that the Albedo effect may have on the climate impacts of biofuels.

3.1 The revised EU framework - Assuming Carbon Neutrality

Even if we employ the basic assumption of carbon neutrality for combustion of biomass, there will usually be fossil fuel emissions associated with the harvesting, transport and refining of biofuels. Thyholt⁹ presented emission factors for a number of biofuels taking such use of fossil fuels into account. The EU commission has recently presented a revised methodology¹⁰ for calculation of greenhouse gas emissions from various biofuels. The 5-page long methodology is referred in Appendix 1 of this paper, and Appendix 2 refers typical EU emission factors using this methodology.

The figure below illustrates the large variations that may be found among biofuels from different areas, and among different kinds of biofuels.

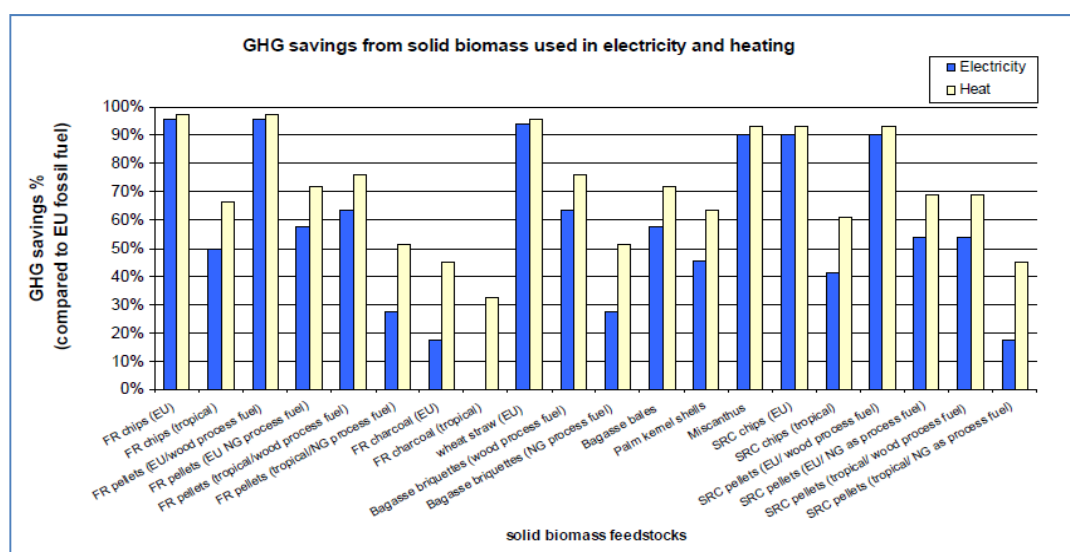


Figure 8 EU Commission methodology

The effects of changes in land use is accounted for in this methodology, but only to the extent that the change of land use has an effect on greenhouse gas emissions. Changes in land use that gives *surface property changes without emission changes*¹¹ are not accounted for.

⁹ Marit Thyholt, *Varmeforsyning til lavenergiboliger i områder med fjernvarmekonsesjon*, PhD Thesis, NTNU, Trondheim, 2006

¹⁰ REPORT FROM THE COMMISSION TO THE COUNCIL AND THE EUROPEAN PARLIAMENT on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling, Brussels, 2010. http://ec.europa.eu/energy/renewables/transparency_platform/doc/2010_report/com_2010_0011_3_report.pdf

¹¹ Including e.g. the Albedo effect, changes in evapotranspiration or in emission of aerosol precursors

The table below presents default values for some common solid and gaseous biofuels. A number of others are found in Appendix 2. Note the impact of process fuel (natural gas or wood) on the default values.

Specific CO₂ emissions from selected biofuels - default values		
BIOFUEL TYPE	gCO₂/MJ	gCO₂/kWh
GROT wood chips	1	3,6
EU Wood chips	4	14,4
GROT pellets / briquettes (1)	2	7,2
EU Wood pellets / briquettes (1)	4	14,4
EU Wood pellets / briquettes (2)	22	79,2
Wheat straw	2	7,2
Biogas from wet manure	8	28,8
Biogas from dry manure	7	25,2
(1) Using wood as process fuel		
(2) Using natural gas as process fuel		
GROT = Wood residue		
EU Wood= European temperate		

Figure 9 Selected specific emissions of solid and gaseous biofuels

This methodology is not discussed in any more detail here in this paper. Interested readers are referred to Appendix 1. Typical results for gaseous and solid biofuels are listed in Appendix 2.

For comparison with liquid biofuels, see Appendix 4. Typical present liquid biofuels in the EU market (i.e. 1st generation liquid biofuels) have CO₂-equivalent emissions in the ranges:

- Ethanol: 24 g/MJ (sugar cane based) – 70 g/MJ (wheat based)
- Biodiesel: 14 g/MJ (waste oils) – 68 g/MJ (palm oil with unspecified process fuel)
- Oils: 14 g/MJ (waste oils) – 62 g/MJ (hydrotreated palm oil with unspec. process fuel)

For 2nd generation biofuels, which are not yet present in significant amounts in the EU market, the following emissions are estimated:

- Ethanol: 13 g/MJ (wheat straw) – 25 g/MJ (farmed wood)
- Biodiesel: 4 g/MJ (waste wood) – 6 g/MJ (farmed wood)
- DME and methanol: 5 g/MJ (waste wood) – 7 g/MJ (farmed wood)

Østfoldforskning ¹² has published data for wood based ethanol produced by Borregaard in Sarpsborg, Norway, that lead to specific CO₂-emissions in the range 14 g/MJ (96% ethanol) – 29 g/MJ (99% ethanol).

3.2 Carbon Neutrality vs. Carbon Debt and Payback Time

The notion that biofuels are carbon neutral created a rapidly growing global market for biofuels from the late 1990ies on. Gradually the awareness was established that some biofuels, e.g. plantation bio-oils from tropical regions, in fact could have rather negative carbon balances, when emissions from land use change were included (e.g. burning of rainforest, erosion and oxidation of carbon rich soil). This awareness leads to closer scrutiny of other biofuel resources.

In Norway, a large debate was initiated addressing the fact that the atmosphere does not distinguish between CO₂ from fossil origin and CO₂ from biogenic sources – one is as bad as the other when it

¹² Østfoldforskning (2009): See <http://ostfoldforskning.no/uploads/dokumenter/publikasjoner/20.pdf>

comes to their greenhouse gas effect as long as they stay in the atmosphere. Norwegian biofuels are by and large based on forest products, and when a large tree is harvested and used for fuel it takes a long time before an equally large tree has grown to replace the original one. The idea is therefore that for a long time – decades, there will be an excess amount of CO₂ in the atmosphere from this tree until it is fully regrown, and during this time, this excess CO₂ will exhibit its contribution to global warming. KLIF, the Norwegian government agency for climate and pollution control, recently published a report¹³ with calculation of carbon payback times for Norwegian uses of bioenergy, as illustrated in the figure below.

Tabell 4-3 Oppsummering av resultater ved ulik anvendelse av biomasse fra skogen	
	Tilbakebetalingstid (år)
Økt uttak av GROT	
- Lav substitusjonseffekt (0,12 kg CO ₂ /kWh)	15
- Høy substitusjonseffekt (0,34 kg CO ₂ /kWh)	<5
Avvirkning – et granbestand	
- UTEN uttak av GROT	
- Lav substitusjonseffekt (0,12 kg CO ₂ /kWh)	>110
- Høy substitusjonseffekt (0,34 kg CO ₂ /kWh)	100
- MED uttak av GROT	
- Lav substitusjonseffekt (0,12 kg CO ₂ /kWh)	>110
- Høy substitusjonseffekt (0,34 kg CO ₂ /kWh)	95
- Høy substitusjonseffekt og lagring i treprodukter	95
- Høyere substitusjonseffekt gjennom substitusjon av byggematerialer	90
Permanent økt avvirkning – i skogen som helhet	
- Lav substitusjonseffekt (0,12 kg CO ₂ /kWh)	Usikkert, >110
- Høy substitusjonseffekt (0,34 kg CO ₂ /kWh)	Usikkert, >90

Figure 10 "Carbon Payback Times" published by Norwegian authorities (KLIF)

The results from this report show that use of wood waste resources ("GROT"; GRen Og Topp) yields carbon payback times of 5 – 15 years, while logging on the present or on higher level yields carbon payback times on the order of 100 years.

The KLIF report points out that these numbers are "business as usual" estimates where harvested trees will be substituted with new plants of the same sort – a long term stationary state assumption. It also points out that there are possibilities for reducing the payback times by a number of different active forestry measures. One such measure that has recently been proposed¹⁴ is plantation of the spruce species Sitka spruce, which may store significantly more carbon than the ordinary Norwegian spruce species.

The notions of Carbon Debt and Payback time are useful in the sense that they make it clear that the use of bioenergy resources is not without potentially negative greenhouse gas emissions on the short term, and they may help distinguish between different biofuels from different origins. But these concepts offer little help in establishing a framework for comparison among energy carriers; the carbon payback

¹³ KLIF: Skog som biomasseressurs, Oslo, Febr. 2011

¹⁴ Vista Analyse: Samfunnsøkonomiske gevinster av skogreisning med sitkagran, februar 2011

time of fossil resources would e.g. be on the order of millions of years, and compared to this timescale the difference between payback times of 10 years and 100 years may appear insignificant.

What seems to be needed is a framework that can establish the difference among different energy carriers and energy sources with respect to what effect they have on global warming both on shorter and on longer terms.

3.3 The GWP_{bio} index

Cherubini et al 7 recently published a new methodology addressing the need for indicators of the global warming potential of biofuels on different timescales. Besides offering a framework for comparison of biofuels combustion with fossile CO₂ emissions, these authors point out that a major shortcoming of present “payback time” approaches for biofuels is the assumption that all CO₂ released by combustion of biomass has to be re-adsorbed into vegetation for the biomass combustion to be carbon neutral. In reality, they point out, about half of the released CO₂ will be absorbed in the oceans. This ocean absorption will reduce the actual “payback time” – the time elapsed from release of a certain quantity of CO₂ into the atmosphere until a similar amount is re-adsorbed – to vegetation or to the oceans.

The Cherubini methodology extends the well established mathematical framework for calculation of the global warming potential of any greenhouse gas relative to CO₂ over a given time horizon TH, which may be mathematically expressed as

$$GWP_i = \frac{AGWP_i}{AGWP_{CO_2}} = \frac{C_0 \int_0^{TH} \alpha_i y_i(t) dt}{C_0 \int_0^{TH} \alpha_{CO_2} y_{CO_2}(t) dt}$$

Figure 11 Definition of Global Warming Potential

where $y_i(t)$ is the time dependent atmospheric decay function for greenhouse gas i , α_i is the radiative efficiency of the gas and C_0 is its initial concentration. For further descriptions on how the radiative efficiency and the atmospheric decay functions are modeled, the reader is referred to the original Cherubini paper, since the purpose here is to highlight principles rather than to elaborate on mathematical details.

The main contribution of the paper by Cherubini et al is the definition of a separate atmospheric decay function $y_i(t)$ for CO₂ from biomass: An *additional re-vegetation carbon sink* is defined for CO₂ from biomass, assuming a rotation time r (the time needed to re-vegetate back to the initial state) and a Gaussian re-vegetation distribution centered around $r/2$. This carbon sink is then added to the other carbon sinks already defined for CO₂ in the atmospheric decay function. The two major parameters describing GWP_{bio} – the global warming potential index for biomass, are thus the rotation time r and the time horizon **TH**.

Cherubini et al demonstrate three alternative atmospheric decay functions, all of them based on impulse response functions (i.e. the biomass CO₂ release is instantaneous, but the atmospheric decay occurs over time), where each function is associated with a particular set of carbon sinks:

1. The OVIRF model assumes that CO₂ is removed from the atmosphere by re-vegetation only. This model would resemble the simple “payback time” approach described earlier in this paper.
2. The VIRF model in addition adds the oceans as a carbon sink.
3. The FIRF model adds both oceans and other terrestrial sinks, including re-vegetation of the harvested area.

Appendix 3 of this paper lists computed results for all these three models as functions of rotation time and time horizon. The figure below shows a sorted set of results from Appendix 3, using the FIRF model, which appears to be the most realistic one:

EXAMPLES:
Tipping point perspective: (TH = 20)
R = 10 => BioGWP = 0,22
R = 20 => BioGWP = 0,47
R = 40 => BioGWP = 0,80
Kyoto perspective: (TH = 100)
R = 50 => BioGWP = 0,21
R = 100 => BioGWP = 0,43

Figure 12 BioGWP examples, as a function of rotation time and time horizon

These results seem to indicate that if the rotation time equals the time horizon, then the contribution to global warming from combustion of biomass will be on the order of half the contribution from similar emissions from fossil fuels. If the rotation time is only half of the time horizon, the contribution from biomass combustion will be even smaller; on the order of 1/5 of that of fossil fuels.

Should the rotation time however be significantly higher than the time horizon, then the global warming potential of biomass combustion would asymptotically approach that of fossil fuels, on an equal specific CO₂ emission basis. However, since some fossil fuels (such as natural gas) have significantly lower specific CO₂ emissions than biofuels, the global warming potential of some fossil fuels (such as natural gas) could be less than that of biomass in cases where the rotation time is long and the time horizon is short.

3.4 The Albedo effect – climate impact without greenhouse gas emissions

Harvesting of biomass involves large surface areas, and when large trees are removed, this impacts the surface properties of the harvested forest area. This is particularly true for northern (boreal) forests, where snow cover may be present parts of the year. A boreal winter / spring forest will appear dark compared to the white open plains that will replace the dark forest-covered surface after harvesting. Snow covered white plains will reflect a much higher portion of the incoming sunlight than dark forests, and this has an impact on the local heat balance: Incoming sunlight that is merely reflected will not heat the surface, and it will not be trapped by greenhouse gases on its way back out of the atmosphere. Sunlight that is absorbed will, on the other hand, to a large degree be converted to heat. This heat will partly warm up the surface, and the part of it that is emitted back to the atmosphere will also partially be trapped by greenhouse gases. The portion of the incoming sunlight that is reflected by a surface is termed the *albedo* of this surface.

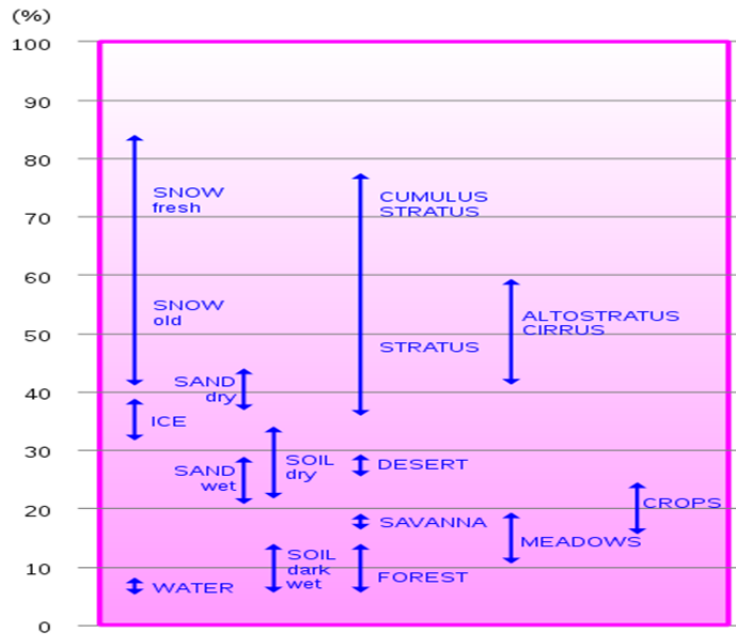


Figure 13 Albedo ranges for different natural surfaces

Forests will typically absorb around 90% of the incoming sunlight and reflect only 10%, while a fresh snow cover is on the other end of the scale, and may absorb as little as 20% of the incoming sunlight.

In 2007, Bala et al.¹⁵ published a paper where they examined the climate implications of large scale deforestation in different parts of the world. In their model calculations, they included the CO₂ emissions resulting from deforestation, and they included also the albedo effects that the deforestation would result in, as well as changes in evapotranspiration and cloud cover. They concluded that large scale deforestation in tropical regions would lead to increased global warming, but *at high latitudes* the albedo effect and changes in evapotranspiration would overwhelm the effect of increased CO₂ emissions and lead to **global cooling**. In temperate regions the climate effect of large scale deforestation would be marginal. The figure below illustrates some of Bala et al's results:

¹⁵ G. Bala et al: *Combined climate and carbon-cycle effects of large-scale deforestation*, Proceedings of the National Academy of Sciences , Vol. 104, No 16, 2007

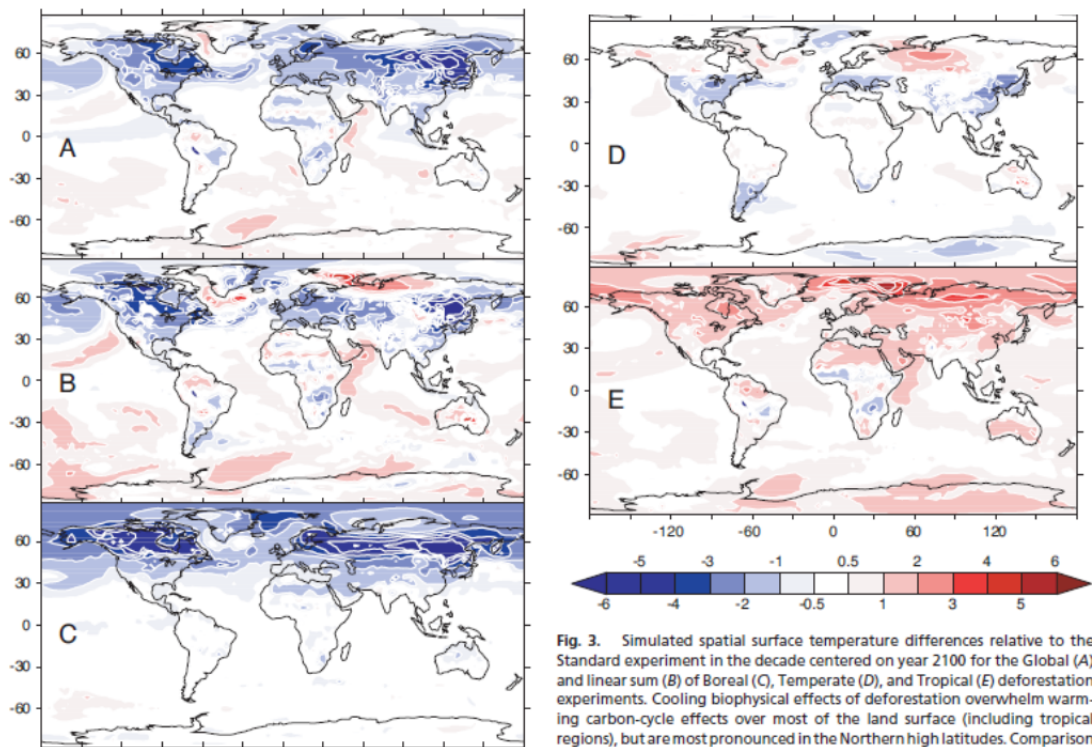


Figure 14 Global cooling and warming as a result of large scale deforestation¹⁵

A large number of publications have later addressed these issues, most recently a paper analyzing Norwegian condition was published by Bright et al. ¹⁶. The Bright paper is very cautious in stating any firm conclusions and points to the need for further research on this topic, but the results they present demonstrate that

- “we see that the combined effect of a changing forest albedo plus fossil fuel substitution leads to a near-climate-neutral system”
- “We showed that the negative albedo forcing due to cumulative effects of albedo changes in forests equaled or exceeded the positive carbon cycle forcing in the short term”.
- “Results reinforce general conclusions drawn in other literature. . . . that the cooling effects of albedo change in high latitude boreal regions such as Norway are important to consider before sound land use and bioenergy policies are to be implemented in those regions.”

3.5 Conclusions and recommendations for biofuels

There is clearly not established a scientific consensus on the global warming effects of biofuels yet. It is therefore challenging to give definite recommendations for which specific emission factors to use at this point in time. The UN IPCC has signaled that their next report, due to be published in 2013, will contain a more thorough examination of Land Use effects, including Albedo considerations. Until this consensus report is available, it is probably wise to be conservative: The present recommendations from the IPCC view Bioenergy as both carbon neutral and climate neutral. We have earlier in this paper seen that

¹⁶ Ryan M. Bright, Anders Hammer Strømman and Glen Peters: *Radiative Forcing Impacts of Boreal Forest Biofuels: A Scenario Study for Norway in Light of Albedo*, Env. Sci & Tech, 2011

notions such as Carbon Debt and Payback Time have somehow discredited this view, but we have also shown that Payback Time calculations need to account for CO₂ absorption in the oceans to make any sense, and we have seen that non-greenhouse-gas effects such as the Albedo effect may overwhelm all greenhouse gas effects under typical Norwegian conditions. A reasonable standpoint under these circumstances is to conclude that none of the above mentioned challenging views on how to consider the global warming effects of biomass combustion are yet backed by sufficient scientific proof to warrant a departure from the initial point of view: Combustion of biomass should still basically be viewed as being climate neutral. Until further notice.

It would however not be wise not to distinguish between different biofuels where these provably have different extents of fossil fuel consumption associated with their harvesting, processing, transport and use. It is therefore at this point recommended to adopt a framework based on the basic assumption of Carbon Neutrality for biofuels, but accounting for the use of fossil fuels. The most recent revised framework that accounts for these factors – the EU guidelines pointed to initially in this paper, are referred to in Appendices 1 and 2.

4. District Heating

In this section of the report we will examine some issues related to the greenhouse gas emissions from District Heating systems. District Heating makes use of a variety of different energy sources and energy carriers, each with their individual greenhouse gas emissions associated, and the relative use of these different sources and carriers will change over time. It is therefore not possible to come up with one single figure covering all cases; each district heating system must be analyzed separately.

The key questions we raise here are:

- Will it under present Norwegian conditions be reasonable to view district heating in general as Waste Heat utilization, and if so: Will it be reasonable to assume zero greenhouse gas emissions?
- Waste incineration is a major part of district heating in Norway. What are the true greenhouse gas emissions from this source?

4.1 District heating - viewed as waste heat utilization

Since the first European District Heating plant was established in Dresden in 1900 (a coal based steam power plant), the development of District Heating in Europe has been closely associated with efficient generation of electric power (CHP). In Sweden, the first ten district heating system involved oil-fired CHP plants. In Denmark, a country heavily reliant on thermal power production, district heating has been emphasized as an important means of achieving efficient electricity production. In a typical thermal power plant based on coal, electric efficiency will typically be on the order of 40 %, while the remaining 60% of the energy present in the feedstock will be lost as waste heat. In CHP mode, producing heat on a useful temperature level for district heating, the losses may be reduced to around 10 %. It has therefore been customary in Europe to consider district heating as waste heat utilization.

In Norway, thermal power generation has been very modest, so the argument for viewing district heating as waste heat is much weaker here than in countries such as Denmark and Germany. Also, even in cases where district heating *may* be considered to be utilization of waste heat, it would be thermodynamically incorrect to assign a zero greenhouse gas emission to it – particularly if electricity production from the same waste heat could be considered as an alternative: In a steam expansion power generating cycle, power may continue to be produced by steam expansion to steam levels well below district heating temperatures. If steam expansion ends at district heating temperature levels (typically 120 – 130 °C) instead of at the lowest possible condensation temperature (in Norway, most places 30 – 40 °C or lower), this leads to a reduction in the amount of electric power produced, typically a reduction on the order of 20 – 25 %. This implies that from a thermodynamic point of view, ***district heating viewed as waste heat utilization*** should on these temperature levels in order to be thermodynamically stringent be assigned greenhouse gas emissions corresponding to ***20 – 25% of the greenhouse gas emissions associated with consumption of electric power.***

4.2 Can district heating partly be viewed as undesired byproduct destruction?

Waste incineration is a major contributor to district heating in Norway. It has frequently been argued that this heat source should be viewed as having zero greenhouse gas emissions, since waste will inevitably have to be destroyed, and incineration is assumed to be the destruction method with the smallest associated greenhouse gas emissions. The actual greenhouse gas emissions, it has been argued, should be assigned to the producers of the waste, since the production of this “product” would

inevitably lead to greenhouse gas emissions. Such a view has a number of problematic issues associated with it:

- *The polluter should pay*: This established principle states that it is the one who emits who is responsible for the emissions. Assigning zero greenhouse gas emissions to waste incineration would be a direct violation of this well established principle.
- What about our oil exports? It would be a true challenge to attempt to assign greenhouse gas emissions from waste incineration to the waste producers, without invoking questions as to whether this should reflect a **general** principle that would ultimately include the inevitable greenhouse gas emissions from Norwegian oil and gas exports.
- Are the **present** greenhouse gas emissions from waste incineration inevitable? Waste reduction, increased material recycling, as well as alternative thermal destruction methods such as gasification and pyrolysis will often hold the promise of yielding even smaller emissions than incineration.
- Undesired byproduct or tradable commodity? Until recently there was an emission tax on waste incinerated in Norway. This tax has now been removed to even out the playing field with respect to competition for Norwegian waste from Swedish district heating plants. This clearly demonstrates that waste for incineration is no longer an undesired byproduct that needs to be dealt with locally – it has become a tradable energy commodity with international demand.

We therefore suggest that **waste should be considered as an ordinary energy commodity**, and that waste incineration should be assigned greenhouse gas emissions at face value in accordance with the amount of greenhouse gases that are actually emitted.

4.3 The fossil fuel contents of incinerated waste

Waste for incineration is a mixture of renewable constituents and components of fossil origin. Assuming that the renewable constituents should be viewed as having zero greenhouse gas emissions – like biofuels in principle, the determination of the share of materials with fossil origin would be required.

Dokka, Wigenstad and Lien ¹⁷ reported specific CO₂ emissions of **211 grams per kWh heat** from waste incineration, based on the following assumptions:

- 25% plastics content by weight in the waste, corresponding to 50% fossil energy.
- 85% efficiency in incineration (produced heat, relative to input heat content; LHV), and 70% energy utilization (delivered, relative to produced.)
- 1 kg plastics give 3.15 kg CO₂, and 13 kWh heat

KLIF ¹⁸ and Mepex ¹⁹ state that the CO₂ emissions from waste incineration in Norway is 0.41 kg per ton of waste. The table below illustrates what CO₂ emissions per kWh this would result in for representative performance factors and three different representative energy contents of the waste:

¹⁷ Dokka, T.H., Wigenstad, T. and Lien, K.M.: Fremtidens energiløsning i større boligutviklingsprosjekter – Jåtten Øst II som case, Prosjektrapport 35, SINTEF Byggforsk, 2009.

¹⁸ KLIF, Klimakur 2020 Sektorrapport Avfall, 2010

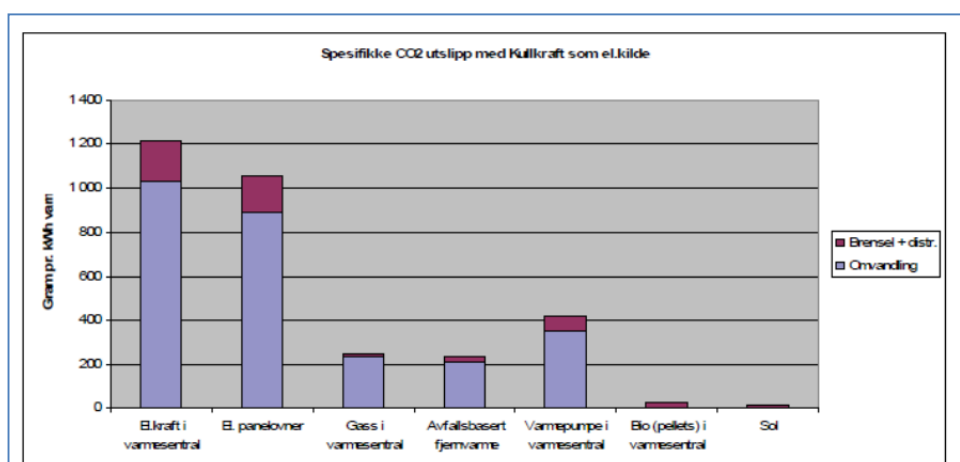
¹⁹ MEPEX Consult AS: Energitensialet i nedbrytbart avfall i Norge, 2009

Specific CO ₂ emissions from waste incineration			
CO ₂ emissions per ton waste, ton	0,41	0,41	0,41
LHV of waste, MWh / tonn	2,9	2,8	3,1
Boiler efficiency	0,85	0,85	0,85
Sold energy / produced energy	0,75	0,75	0,75
Sold energy per ton waste, MW	1,85	1,79	1,98
CO₂ emissions pr. MWh, ton	0,22	0,23	0,21

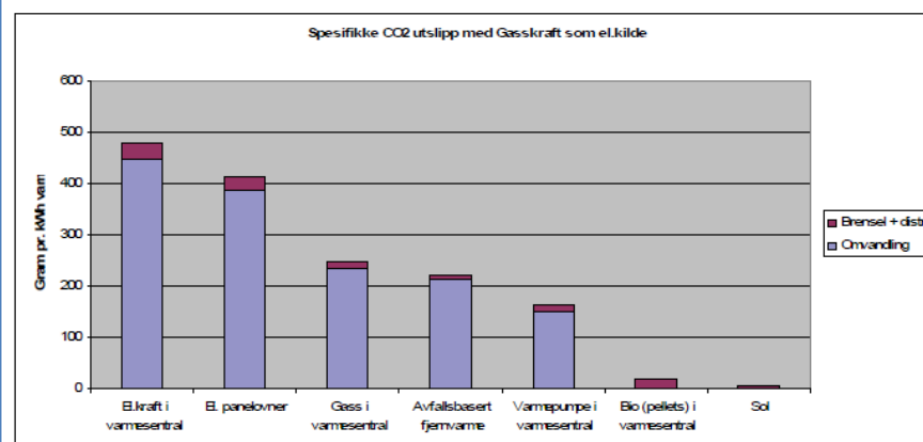
Figure 15 Specific CO₂ emissions from waste incineration (derived from KLIF ¹⁸)

This demonstrates that the results of Dokka, Wigenstad and Lien are for all practical purposes the same as those of KLIF and Mepex.

This implies that there will in practice be **only minor differences** between greenhouse gas emissions from **waste incineration** and from combustion of **natural gas**. This is illustrated in the figure below, taken from Dokka, Wigenstad and Lien ¹⁷.



FIGUR 8-1 Spesifikke CO₂-utslipp pr kWh med antatt kullkraftscenarie.



FIGUR 8-2 Spesifikke CO₂-utslipp pr kWh med antatt gasskraftscenarie.

Figure 16 Results from Dokka, Wigenstad and Lien¹⁷

4.4 The present composition of District Heating in Norway

Figure 17 below shows the composition of energy sources and carriers for district heating in Norway 1998 – 2007. On the average, waste incineration accounts for more than 50% of the overall production and is relatively constant, but the shares of electricity and fossil fuels vary significantly from year to year. This annual variation occurs because electricity and oil / gas are used as peak load energy sources, and is determined by annual demand variations due to annual variations of average winter temperatures, as well as by the relative price of electricity and oil / gas. Natural gas has to a large extent replaced oil in peak load application over the past few years.

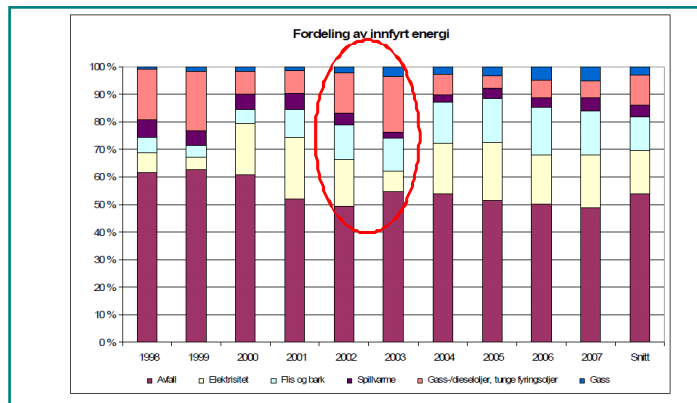
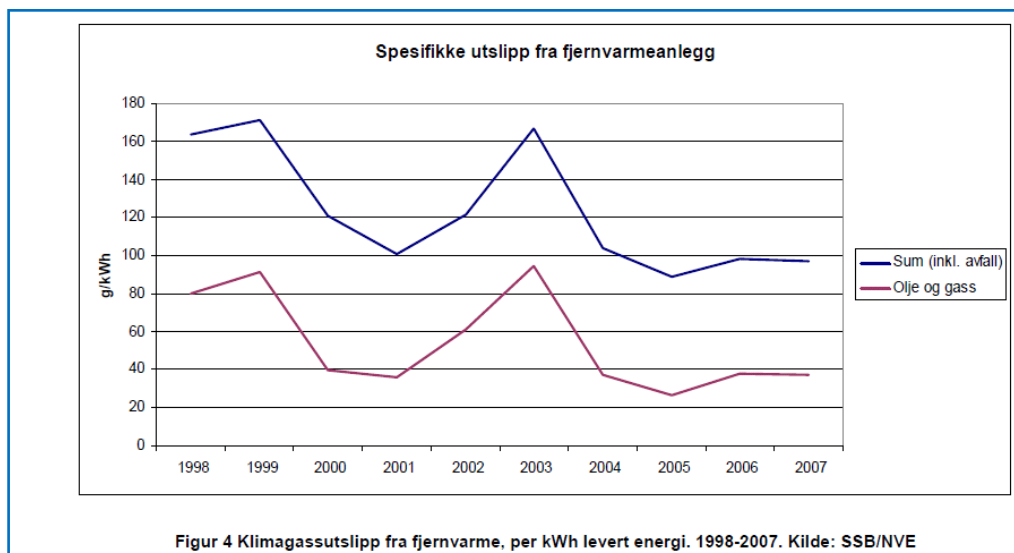


Figure 17 District Heating energy source distribution (Source: NVE ²⁰, 2010)

If emissions from electricity consumption in Norway are viewed as being close to zero, this will then result in large annual variations in calculated greenhouse gas emissions, as illustrated in Figure 18.



Figur 4 Klimagassutslipp fra fjernvarme, per kWh levert energi. 1998-2007. Kilde: SSB/NVE

Figure 18 Annual variation of greenhouse gas emissions from District Heating in Norway, NVE (2010);
(Note: Electricity assumed to have zero greenhouse gas emissions)

²⁰ NVE, 2010: Klimagassutslipp fra fjernvarme, tiltak og virkemidler. Et innspill til Klimakur 2020.

In their contribution to Klimakur 2020 ²⁰, NVE presented the following qualitative conclusion regarding the present climate effect of district heating:

En betraktning av om innføring av fjernvarme fører til økte eller minskete klimagassutslipp er svært avhengig av om man mener bruk av elektrisitet fører til utslipp av klimagasser. En mulig betraktning er at alternativet til bruk av el i Norge er eksport til våre naboland, som har til dels store innslag av fossile primærenergikilder i kraftforsyningen.

Konklusjonen er at fjernvarme i seg selv ikke automatisk er et godt klimatiltak, i alle fall ikke før det er gjennomført tiltak som fjerner utslippene. Om fjernvarme har en god eller dårlig klimaeffekt er avhengig av hva som erstattes og hva som er realistiske alternative tiltak, og må vurderes i det enkelte tilfelle.

(Translation: "Whether introduction of District Heating leads to higher or lower greenhouse gas emissions depends on whether one considers the use of electricity to lead to higher greenhouse gas emissions. A possible point of view is that the alternative to use of electricity in Norway is export to our neighbor countries, which have considerable portions of fossil primary energy sources in their electric power supply. The conclusion is that District Heating is not automatically a good greenhouse gas reduction measure, at least not until measures are made to reduce its emissions. Whether District Heating gives a positive or negative global warming effect depends on what it replaces and what are the alternative measures, and this has to be considered in each specific case.")

Figure 19 NVE's general conclusions on District Heating regarding greenhouse gas emissions in Klimakur 2020

4.5 The future composition of District Heating in Norway

To reduce the greenhouse gas emissions from district heating in the future, present **fossil peak load capacity should be phased out**. If electricity consumption is considered to imply indirect greenhouse gas emissions, electric peak load capacity should also be phased out. This presently seems to imply **greater use of biofuels in peak load applications** in the future, since other renewable energy forms in general are difficult and expensive to store for the periods where peak capacity is needed.

Base load capacity will also need to be re-examined in the future, in particular in scenarios where 80 % reductions or more in greenhouse gas emission could be required. One should be aware that in typical Norwegian district heating plants, with waste incineration as base load and natural gas as peak load, specific greenhouse gas **emissions may not differ much between base load and peak load**. This is primarily due to the high plastics contents (50% on energy basis) of incinerated waste. In this present situation, it is a paradox that further expansion of waste based base load capacity is presently subsidized ²¹, and so is conversion away from natural gas based peak load.

Most of the fossil material in waste is comprised of plastics. KLIF ¹⁸ argues that further material recycling of plastics from waste would be possible. Presently it is estimated that 27% of the plastics in waste are recycled, and KLIF argues that it could be possible to increase this to 40% by 2020. Plastics from waste that is not recycled is assumed to go to incineration. The general use of disposable plastics in society is however presently increasing at an annual rate of 3.5%, and this implies that *even if we succeed in increasing the material recycling, there may be more plastics in the waste in 2020 than there is in 2012*. It is therefore important to find alternatives to incineration for waste containing large amounts of plastics. Otherwise, the CO₂ emissions from waste based district heating systems could end up having specific greenhouse gas emissions that are significantly higher than those from combustion of natural gas.

²¹ Through investment grants from Enova for new and expanded waste incineration plants

Alternatives to waste incineration that could reduce base load greenhouse gas emissions could for example include geothermal heat, solar heat, industrial waste heat, as well as the less expensive ones among the biofuels.

4.6 Conclusions and recommendations on District Heating

We recommend that in general, district heating should not be viewed as waste heat utilization, but should instead be analyzed on the basis of the actual greenhouse gas emissions associated. Neither should waste incineration based district heating be viewed as inevitable byproduct destruction: Waste for incineration is presently an internationally tradable commodity, and should preferably be utilized where it gives maximum energy per unit greenhouse gas emitted.

With the present composition of incinerated waste (50% fossil on energy basis), specific greenhouse gas emissions from waste incineration are on the same level as combustion of natural gas. Waste incineration based district heating systems do therefore presently have only minor differences in specific greenhouse gas emissions between base load (waste) and peak load (gas).

Future reductions in peak load specific emissions are possible if present natural gas is substituted by biofuels. Future reductions in base load specific emissions would either require that present portions of waste incineration are reduced, or that improved recycling solutions are found for major portions of the plastics presently found in waste. Alternatives to waste incineration that could reduce base load greenhouse gas emissions could for example include geothermal heat, solar heat, industrial waste heat, as well as the less expensive ones among the biofuels.

APPENDICES

Appendix 1: EU Commission procedure for calculation of emission factors for biofuels

ANNEX I – Methodology for calculating greenhouse gas performance of solid and gaseous biomass used in electricity, heating and cooling

- 1a. Greenhouse gas emissions from the production of solid and gaseous biomass fuels, before conversion into electricity, heating and cooling, shall be calculated as:

$$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr},$$

where

E = total emissions from the production of the fuel before energy conversion;

e_{ec} = emissions from the extraction or cultivation of raw materials;

e_l = annualised emissions from carbon stock changes caused by land use change;

e_p = emissions from processing;

e_{td} = emissions from transport and distribution;

e_u = emissions from the fuel in use, that is greenhouse gases emitted during the combustion of solid and gaseous biomass;

e_{sca} = emission savings from soil carbon accumulation via improved agricultural management;

e_{ccs} = emission savings from carbon capture and geological storage, and;

e_{ccr} = emission savings from carbon capture and replacement.

Emissions from the manufacture of machinery and equipment shall not be taken into account.

- 1b. Greenhouse gas emissions from the use of solid and gaseous biomass in producing electricity, heating or cooling including the energy conversion to electricity and/ or heat or cooling produced shall be calculated as follows:

For energy installations delivering only useful heat:

$$EC_h = \frac{E}{\eta_h}$$

For energy installations delivering only electricity:

$$EC_{el} = \frac{E}{\eta_{el}}$$

For energy installations delivering only useful cooling:

EN

EN

$$EC_c = \frac{E}{\eta_c}$$

Where:

EC_h = Total greenhouse gas emissions from the final energy commodity, that is heating.

EC_{el} = Total greenhouse gas emissions from the final energy commodity, that is electricity.

EC_c = Total greenhouse gas emissions from the final energy commodity, that is cooling

η_{el} = The electrical efficiency, defined as the annual electricity produced divided by the annual fuel input.

η_h = The thermal efficiency, defined as the annual useful heat output, that is heat generated to satisfy an economically justifiable demand for heat, divided by the annual fuel input.

η_c = The thermal efficiency, defined as the annual useful cooling output, that cooling generated to satisfy an economically justifiable demand for cooling, divided by the annual fuel input.

Economically justifiable demand shall mean the demand that does not exceed the needs of heat or cooling and which would otherwise be satisfied at market conditions.

For the electricity coming from energy installations delivering useful heat:

$$EC_{el} = \frac{E}{\eta_{el}} \left(\frac{C_{el} \cdot \eta_{el}}{C_{el} \cdot \eta_{el} + C_h \cdot \eta_h} \right)$$

For the useful heat coming from energy installations delivering electricity:

$$EC_h = \frac{E}{\eta_h} \left(\frac{C_h \cdot \eta_h}{C_{el} \cdot \eta_{el} + C_h \cdot \eta_h} \right)$$

Where:

C_{el} = Fraction of exergy in the electricity, or any other energy carrier other than heat, set to 100 % ($C_{el} = 1$).

C_h = Carnot efficiency (fraction of exergy in the useful heat).

Carnot efficiency, C_h , for useful heat at different temperatures:

$$C_h = \frac{T_h - T_0}{T_h}$$

Where:

T_h = Temperature, measured in absolute temperature (kelvin) of the useful heat at point of delivery as final energy

T_0 = Temperature of surroundings, set at 273 kelvin (equal to 0 °C)

For $T_h < 150$ °C (423 kelvin), C_h is defined as follows:

C_h = Carnot efficiency in heat at 150 °C (423 kelvin), which is: 0.3546

2. Greenhouse gas emissions from solid and gaseous biomass fuels for electricity, heating and cooling purposes, EC , shall be expressed in terms of grams of CO_2 equivalent per MJ of final energy commodity (heat, cooling or electricity), gCO_{2eq}/MJ .
3. Greenhouse gas emission savings from heat, cold and electricity being generated from solid and gaseous biomass shall be calculated as:

$$SAVING = (EC_{F(h,e,l,c)} - EC_{h,e,l,c}) / EC_{F(h,e,l,c)}$$

where

$EC_{h,e,l,c}$ = total emissions from the heat, cooling or the electricity; and

$EC_{F(h,e,l,c)}$ = total emissions from the fossil fuel comparator for heat, cooling or electricity.

4. The greenhouse gases taken into account for the purposes of point 1 shall be CO_2 , N_2O and CH_4 . For the purpose of calculating CO_2 equivalence, those gases shall be valued as follows:

CO_2 : 1

N_2O : 296

CH_4 : 23

5. Emissions from the extraction, harvesting or cultivation of raw materials, e_{ee} , shall include emissions from the extraction, harvesting or cultivation process itself; from the collection of raw materials; from waste and leakages; and from the production of chemicals or products used in extraction or cultivation. Capture of CO_2 in the cultivation of raw materials shall be excluded. Certified reductions of greenhouse gas emissions from flaring at oil production sites anywhere in the world shall be deducted. Estimates of emissions from cultivation or harvesting may be derived from the use of averages calculated for smaller geographical areas than those used in the calculation of the default values, as an alternative to using actual values.

EN

EN

6. Annualised emissions from carbon stock changes caused by land-use change, e_l , shall be calculated by dividing total emissions equally over 20 years. For the calculation of those emissions the following rule shall be applied:

$$e_l = (CS_R - CS_A) \times 3,664 \times 1/20 \times 1/P - e_B,$$

where

e_l = annualised greenhouse gas emissions from carbon stock change due to land-use change (measured as mass of CO₂-equivalent per unit solid and gaseous biomass energy);

CS_R = the carbon stock per unit area associated with the reference land use (measured as mass of carbon per unit area, including both soil and vegetation). The reference land use shall be the land use in January 2008 or 20 years before the raw material was obtained, whichever was the later;

CS_A = the carbon stock per unit area associated with the actual land use (measured as mass of carbon per unit area, including both soil and vegetation). In cases where the carbon stock accumulates over more than one year, the value attributed to CS_A shall be the estimated stock per unit area after 20 years or when the crop reaches maturity, whichever the earlier;

P = the productivity of the crop (measured as solid and gaseous biomass energy per unit area per year); and

e_B = bonus of 29 g CO_{2eq}/MJ solid and gaseous biomass if biomass is obtained from restored degraded land under the conditions provided for in point 7.

7. The bonus of 29 g CO_{2eq}/MJ shall be attributed if evidence is provided that the land:

(a) was not in use for agriculture or any other activity in January 2008; and

(b) falls into one of the following categories:

(i) severely degraded land, including such land that was formerly in agricultural use;

(ii) heavily contaminated land.

The bonus of 29 g CO_{2eq}/MJ shall apply for a period of up to 10 years from the date of conversion of the land to agricultural use, provided that a steady increase in carbon stocks as well as a sizable reduction in erosion phenomena for land falling under (i) are ensured and that soil contamination for land falling under (ii) is reduced.

8. The categories referred to in point 7(b) are defined as follows:

(a) "severely degraded land" means land that, for a significant period of time, has either been significantly salinated or presented significantly low organic matter content and has been severely eroded;

(b) "heavily contaminated land" means land that is unfit for the cultivation of food and feed due to soil contamination.

Such land shall include land that has been the subject of a Commission decision in accordance with the fourth subparagraph of Article 18(4) of Directive 2009/28/EC.

9. In accordance with Annex V.C point 10 of Directive 2009/28/EC, the Commission guidelines for the calculation of land carbon stocks adopted in relation to that Directive, drawing on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories — volume 4, shall serve as the basis for the calculation of land carbon stocks.

10. Emissions from processing, e_p , shall include emissions from the processing itself; from waste and leakages; and from the production of chemicals or products used in processing.

In accounting for the consumption of electricity not produced within the fuel production plant, the greenhouse gas emission intensity of the production and distribution of that electricity shall be assumed to be equal to the average emission intensity of the production and distribution of electricity in a defined region. By derogation from this rule, producers may use an average value for an individual electricity production plant for electricity produced by that plant, if that plant is not connected to the electricity grid.

11. Emissions from transport and distribution, e_{td} , shall include emissions from the transport and storage of raw and semi-finished materials and from the storage and distribution of finished materials. Emissions from transport and distribution to be taken into account under point 5 shall not be covered by this point.

12. Emissions from the fuel in use, e_u , shall be taken to be zero for solid and gaseous biomass.

13. Emission saving from carbon capture and sequestration, e_{ccs} , that have not already been accounted for in e_p , shall be limited to emissions avoided through the capture and sequestration of emitted CO₂ directly related to the extraction, transport, processing and distribution of fuel.

14. Emission saving from carbon capture and replacement, e_{ccr} , shall be limited to emissions avoided through the capture of CO₂ of which the carbon originates from biomass and which is used to replace fossil-derived CO₂ used in commercial products and services.

15. Where a fuel production process produces, in combination, the energy carrier for which emissions are being calculated and one or more other products ("co-products"), greenhouse gas emissions shall be divided between the energy carrier or its intermediate product and the co-products in proportion to their energy content. For the accounting of useful heat as co-product, the allocation between the useful heat and other co-products shall be made using the Carnot efficiency (C), where all other co-products than heat has a C equal to 1.

$$A_i = \frac{E}{\eta_i} \left(\frac{C_i \cdot \eta_i}{C_i \cdot \eta_i + C_h \cdot \eta_h} \right)$$

Where:

A_i = Allocated GHG emissions at allocation point to (co-)product i

E = Total GHG emissions up to allocation point

η_i = The fraction of co-product or product, measured in energy content, defined as the annual amount of co-product or product produced divided by the annual energy input.

η_h = The fraction of heat produced together with other co-products or products, defined as the annual useful heat output divided by the annual energy input.

C_i = Fraction of exergy in the energy carrier (else than heat), equal to 1

C_h = Carnot efficiency (fraction of exergy in the useful heat).

Carnot efficiency, C_h , for useful heat at different temperatures:

$$C_h = \frac{T_h - T_0}{T_h}$$

Where:

T_h = Temperature, measured in absolute temperature (kelvin) of the useful heat at point of delivery.

T_0 = Temperature of surroundings, set at 273 kelvin (equal to 0 °C)

For $T_h < 150$ °C (423 kelvin), C_h is defined as follows:

C_h = Carnot efficiency for heat at 150 °C (423 kelvin), which is: 0.3546

16. For the purposes of the calculation referred to in paragraph 15, the emissions to be divided shall be $e_{ec} + e_l$, + those fractions of e_p , e_{id} and e_{ee} that take place up to and including the process step at which a co-product is produced. If any allocation to co-products has taken place at an earlier process step in the life-cycle, the fraction of those emissions assigned in the last such process step to the intermediate fuel product shall be used for this purpose instead of the total of those emissions.

In the case of solid and gaseous biomass, all co-products, including electricity that does not fall under the scope of paragraph 14, shall be taken into account for the purposes of this calculation, except for agricultural crop residues, including straw, bagasse, husks, cobs and nut shells. Co-products that have negative energy content shall be considered to have an energy content of zero for the purpose of the calculation.

Wastes, secondary biomass and primary forest and agricultural crop residues, including tree tops and branches, straw, bagasse, husks, cobs and nut shells, and residues from processing, including crude glycerine (glycerine that is not refined), shall be considered to have zero life-cycle greenhouse gas emissions up to the process of collection of those materials.

In the case of fuels produced in refineries, the unit of analysis for the purposes of the calculation referred to in paragraph 15 shall be the refinery.

17. For solid and gaseous biomass, for electricity production, for the purposes of the calculation referred to in point 4, the fossil fuel comparator $EC_{F(el)}$ shall be 198 gCO_{2eq}/MJ electricity.

For solid and gaseous biomass used for heating production, for the purposes of the calculation referred to in point 4, the fossil fuel comparator $EC_{F(h)}$ shall be 87 gCO_{2eq}/MJ heat.

For solid and gaseous biomass used for cooling through absorption heat pumps, for the purposes of the calculation referred to in point 4, the fossil fuel comparator $EC_{F(c)}$ shall be 57 gCO_{2eq}/MJ cooling.

Appendix 2: Typical EU emission factors using the procedure of Appendix 1

ANNEX II – Typical and default values for solid and gaseous biomass if produced with no net carbon emissions from land use change

Primary solid and gaseous biomass pathways	Typical greenhouse gas emissions (gCO _{2eq} /MJ)	Default greenhouse gas emissions (gCO _{2eq} /MJ)
Wood chips from forest residues (European temperate continental forest)	1	1
Wood chips from forest residues (tropical and subtropical forest)	21	25
Wood chips from short rotation forestry (European temperate continental forest)	3	4
Wood chips short rotation forestry (tropical and sub-tropical e.g. eucalyptus)	24	28
Wood briquettes or pellets from forest residues (European temperate continental forest) – using wood as process fuel	2	2
Wood briquettes or pellets from forest residues (tropical or subtropical forest) – using natural gas as process fuel	17	20
Wood briquettes or pellets from forest residues (tropical or subtropical forest) – using wood as process fuel	15	17
Wood briquettes or pellets from forest residues (European temperate continental forest) – using natural gas as process fuel	30	35
Wood briquettes or pellets from short rotation forestry (European temperate continental forest) – using wood as process fuel	4	4
Wood briquettes or pellets from short rotation forestry (European temperate continental forest) – using natural gas as process fuel	19	22
Wood briquettes or pellets from short rotation forestry (tropical and sub-tropical e.g. eucalyptus) – wood as process fuel	18	22

EN

EN

Wood briquettes or pellets from short rotation forestry (tropical and sub-tropical e.g. eucalyptus) – natural gas as process fuel	33	40
Charcoal from forest residues (European temperate continental forest)	34	41
Charcoal from forest residues (tropical and sub-tropical forest)	41	50
Charcoal from short rotation forestry (European temperate continental forest)	38	46
Charcoal from short rotation forestry (tropical and sub-tropical e.g. eucalyptus)	47	57
Wheat straw	2	2
Bagasse briquettes – wood as process fuel	14	17
Bagasse briquettes – natural gas as process fuel	29	35
Bagasse bales	17	20
Palm kernel	22	27
Rice husk briquettes	24	28
Miscanthus bales	6	7
Biogas from wet manure	7	8
Biogas from dry manure	6	7
Biogas from wheat and straw (wheat whole plant)	18	21
Biogas from maize as whole plant (maize as main crop)	28	34
Biogas from maize as whole plant (maize as main crop) – organic agriculture	16	19

EN

EN

Appendix 3: GWP_{bio} (Cherubini et al)

10 F. CHERUBINI *et al.*

Table 3 GWP_{Bio} index calculated with the three different methods and for three different time horizons: 20, 100 and 500 years

Rotation <i>r</i> (years)	VIRF			OVIRF			FIRF		
	GWP _{bio}	GWP _{bio}	GWP _{bio}	GWP _{bio}	GWP _{bio}	GWP _{bio}	GWP _{bio}	GWP _{bio}	GWP _{bio}
	TH = 20	TH = 100	TH = 500	TH = 20	TH = 100	TH = 500	TH = 20	TH = 100	TH = 500
1	0.04	0.01	0.00	0.03	0.00	0.00	0.02	0.00	0.00
2	0.08	0.02	0.01	0.05	0.01	0.00	0.04	0.01	0.00
4	0.15	0.04	0.01	0.11	0.02	0.01	0.09	0.02	0.00
6	0.23	0.07	0.02	0.16	0.04	0.01	0.13	0.02	0.00
8	0.30	0.09	0.03	0.21	0.05	0.01	0.18	0.03	0.01
10	0.38	0.11	0.03	0.27	0.06	0.01	0.22	0.04	0.01
12	0.45	0.13	0.04	0.32	0.07	0.01	0.27	0.05	0.01
14	0.53	0.15	0.05	0.38	0.08	0.02	0.32	0.06	0.01
16	0.60	0.17	0.05	0.44	0.09	0.02	0.37	0.06	0.01
18	0.68	0.19	0.06	0.50	0.10	0.02	0.42	0.07	0.01
20	0.75	0.22	0.07	0.55	0.12	0.02	0.47	0.08	0.02
22	0.82	0.24	0.07	0.61	0.13	0.03	0.52	0.09	0.02
24	0.89	0.26	0.08	0.66	0.14	0.03	0.56	0.10	0.02
26	0.95	0.28	0.09	0.71	0.15	0.03	0.61	0.10	0.02
28	1.00	0.30	0.09	0.76	0.16	0.03	0.65	0.11	0.02
30	1.05	0.32	0.10	0.80	0.18	0.04	0.68	0.12	0.02
32	1.09	0.34	0.10	0.83	0.19	0.04	0.71	0.13	0.02
34	1.13	0.37	0.11	0.86	0.20	0.04	0.74	0.14	0.03
36	1.16	0.39	0.12	0.89	0.21	0.04	0.76	0.15	0.03
38	1.19	0.41	0.12	0.91	0.22	0.05	0.79	0.15	0.03
40	1.21	0.43	0.13	0.93	0.24	0.05	0.80	0.16	0.03
42	1.23	0.45	0.14	0.95	0.25	0.05	0.82	0.17	0.03
44	1.25	0.47	0.14	0.97	0.26	0.05	0.83	0.18	0.03
46	1.27	0.49	0.15	0.98	0.27	0.06	0.85	0.19	0.04
48	1.28	0.52	0.16	1.00	0.28	0.06	0.86	0.20	0.04
50	1.30	0.54	0.16	1.01	0.30	0.06	0.87	0.21	0.04
52	1.31	0.56	0.17	1.02	0.31	0.06	0.88	0.21	0.04
54	1.32	0.58	0.18	1.03	0.32	0.07	0.89	0.22	0.04
56	1.33	0.60	0.18	1.03	0.33	0.07	0.89	0.23	0.04
58	1.34	0.62	0.19	1.04	0.34	0.07	0.90	0.24	0.04
60	1.35	0.64	0.20	1.05	0.36	0.07	0.90	0.25	0.05
62	1.35	0.67	0.20	1.05	0.37	0.08	0.91	0.26	0.05
64	1.36	0.69	0.21	1.06	0.38	0.08	0.91	0.27	0.05
66	1.36	0.71	0.22	1.06	0.39	0.08	0.92	0.28	0.05
68	1.37	0.73	0.22	1.07	0.41	0.08	0.92	0.29	0.05
70	1.37	0.75	0.23	1.07	0.42	0.09	0.93	0.30	0.05
72	1.38	0.77	0.24	1.08	0.43	0.09	0.93	0.30	0.06
74	1.38	0.79	0.24	1.08	0.44	0.09	0.93	0.31	0.06
76	1.39	0.82	0.25	1.08	0.46	0.09	0.94	0.32	0.06
78	1.39	0.84	0.25	1.09	0.47	0.10	0.94	0.33	0.06
80	1.39	0.86	0.26	1.09	0.48	0.10	0.94	0.34	0.06
82	1.40	0.88	0.27	1.09	0.49	0.10	0.94	0.35	0.06
84	1.40	0.90	0.27	1.09	0.51	0.10	0.95	0.36	0.06
86	1.40	0.92	0.28	1.10	0.52	0.11	0.95	0.37	0.07
88	1.40	0.94	0.29	1.10	0.53	0.11	0.95	0.38	0.07
90	1.41	0.96	0.29	1.10	0.54	0.11	0.95	0.39	0.07
92	1.41	0.98	0.30	1.10	0.55	0.11	0.95	0.39	0.07
94	1.41	0.99	0.31	1.10	0.56	0.12	0.95	0.40	0.07
96	1.41	1.01	0.31	1.10	0.58	0.12	0.96	0.41	0.07
98	1.41	1.03	0.32	1.11	0.59	0.12	0.96	0.42	0.08
100	1.42	1.05	0.33	1.11	0.60	0.12	0.96	0.43	0.08

GWP, global warming potential; VIRF, vegetation impulse response function; OVIRF, ocean and vegetation impulse response function; FIRF, full impulse response function; TH, time horizon.

Appendix 4: Typical EU default emission values for liquid biofuels

The entire calculation procedure for liquid biofuels is presented in EU Directive 2009/28 “On the promotion of the use of energy from renewable sources”, published in the *Official Journal of the European Union*, 5.6.2009, L140/16 – L140/62.

The first table below summarizes typical and default values for biofuels present in the EU market as of 2008. The second table estimates typical and default values of new biofuels, not significantly available in the EU market as of 2008.

Total for cultivation, processing, transport and distribution		
Biofuel and bioliquid production pathway	Typical greenhouse gas emissions (gCO _{2eq} /MJ)	Default greenhouse gas emissions (gCO _{2eq} /MJ)
sugar beet ethanol	33	40
wheat ethanol (process fuel not specified)	57	70
wheat ethanol (lignite as process fuel in CHP plant)	57	70
wheat ethanol (natural gas as process fuel in conventional boiler)	46	55
wheat ethanol (natural gas as process fuel in CHP plant)	39	44
wheat ethanol (straw as process fuel in CHP plant)	26	26
corn (maize) ethanol, Community produced (natural gas as process fuel in CHP plant)	37	43
sugar cane ethanol	24	24
the part from renewable sources of ETBE	Equal to that of the ethanol production pathway used	
the part from renewable sources of TAAE	Equal to that of the ethanol production pathway used	
rape seed biodiesel	46	52
sunflower biodiesel	35	41
soybean biodiesel	50	58
palm oil biodiesel (process not specified)	54	68
palm oil biodiesel (process with methane capture at oil mill)	32	37
waste vegetable or animal oil biodiesel	10	14
hydrotreated vegetable oil from rape seed	41	44
hydrotreated vegetable oil from sunflower	29	32
hydrotreated vegetable oil from palm oil (process not specified)	50	62
hydrotreated vegetable oil from palm oil (process with methane capture at oil mill)	27	29
pure vegetable oil from rape seed	35	36

(source: *Official Journal of the European Union*, 5.6.2009, L140/16 – L140/62, pg. 59)

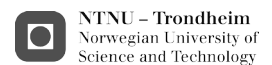
Total for cultivation, processing, transport and distribution

Biofuel and bioliquid production pathway	Typical greenhouse gas emissions (gCO _{2eq} /MJ)	Default greenhouse gas emissions (gCO _{2eq} /MJ)
wheat straw ethanol	11	13
waste wood ethanol	17	22
farmed wood ethanol	20	25
waste wood Fischer-Tropsch diesel	4	4
farmed wood Fischer-Tropsch diesel	6	6
waste wood DME	5	5
farmed wood DME	7	7
waste wood methanol	5	5
farmed wood methanol	7	7
the part from renewable sources of MTBE	Equal to that of the methanol production pathway used	

(source: *Official Journal of the European Union*, 5.6.2009, L140/16 – L140/62, pg. 59)

The Research Centre on Zero emission Buildings (ZEB)

The main objective of ZEB is to develop competitive products and solutions for existing and new buildings that will lead to market penetration of buildings that have zero emissions of greenhouse gases related to their production, operation and demolition. The Centre will encompass both residential and commercial buildings, as well as public buildings.



Partners

NTNU
www.ntnu.no

SINTEF
www.sintef.no

Skanska
www.skanska.no

Weber
www.weber-norge.no

Isola
www.isola.no

Glava
www.glava.no

Protan
www.protan.no

Hydro Aluminium
www.hydro.com

Caverion Norge
www.caverion.no

ByBo
www.bybo.no

Multiconsult
www.multiconsult.no

Brødrene Dahl
www.dahl.no

Snohetta
www.snoarc.no

Forsvarsbygg
www.forsvarsbygg.no

Statsbygg
www.statsbygg.no

Husbanken
www.husbanken.no

Byggenæringens Landsforening
www.bnl.no

Norsk Teknologi
www.norskteknologi.no

Direktoratet for byggkvalitet
www.dibk.no

DuPont
www.dupont.com

NorDan AS
www.nordan.no

Enova
www.enova.no

VELUX
www.velux.com

Entrå
www.entra.no